I. C. 7382 NOVEMBER 1946

UNITED STATES
DEPARTMENT OF THE INTERIOR
J. A. KRUG, SECRETARY

BUREAU OF MINES
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TREATMENT OF ACID MINE WATER FOR BREAKER USE IN THE ANTHRACITE REGION OF PENNSYLVANIA

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

TREATMENT OF ACID MINE WATER FOR BREAKER USE IN THE ANTHRACITE REGION OF PENNSYLVANIA[1]

By L. H. Johnson[2]

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2/ Mining engineer, Safety Division, Bureau of Mines, Wilkes-Barre, Pa.

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INTRODUCTION

The Pennsylvania anthracite industry produced 53 million net tons of anthracite during 1945. Fifty-one million tons was prepared for the commercial market(3),3/ and 2 million tons (consisting of fine sizes) was used for colliery power consumption. Of the total number of tons prepared for market, 17 million tons (33-1/3 percent) was prepared by the use of acid mine water treated with lime.

Mine water from underground workings is pumped, drained, and stored in huge quantities. The mine-drainage systems in the anthracite region handle over 200 billion gallons of water annually, of which 150 billion gallons is pumped to the surface. More than 69 billion gallons of water is impounded in underground pools(1). Much of this water is employed for breaker use, dust-control installations, hydraulic backfilling, combatting mine fires, and aiding in the transportation of anthracite in gently dipping places where sheet iron is used. Roos(4) estimates that 1,100 gallons of mine-water is utilized in the preparation of each ton of anthracite mined.

Purpose of Report

Mine water with low acid content is used without treatment for breaker use, but in many instances the mine water is highly acid and is treated to protect pipe, pumps, valves, tanks, screens, and the metallic lining of chutes from corroding.

The formation of acid in anthracite mines is usually attributed to oxidation of the iron pyrite present in the coal measures. The iron sulfates formed are readily soluble in water, and subsequent oxidation and hydration result in the formation of iron oxide (sulfur mud or yellow-boy) and free sulfuric acid. The presence of an oxidizing agent (ferric iron)

3/ Numbers in parentheses refer to references at the end of the report.

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and a solvent (sulfuric acid) provides an active leaching solution that causes corrosion.

When only highly acid mine water was available for washery use at breakers, the replacement and labor costs required to maintain coal preparation at desired capacity were exorbitant. It was not unusual to replace pipe and other equipment after 3 weeks of service. Many companies used equipment made of extra-heavy metal, and in recent years, equipment made of various acid-resistant alloys to obtain longer, more efficient wear was used. During the recent war, heavy metals and alloys were difficult to obtain; and to enable the industry to maintain peak production, the treatment of mine water by lime for washery use provided a means by which lightweight materials could be used because of less corrosion.

The first installation for lime treatment of mine water used to prepare anthracite was put into operation in 1932. Lime precipitates ferric sulfate and hastens the oxidation of the ferrous sulfate, with subsequent precipitation of additional ferric sulfate.

A study of lime-treatment systems in use was conducted to correlate the methods of treating mine water, determine the range and effect of treatment, determine the types of lime in use, correlate the testing procedures, and obtain available cost data that would aid interested persons in the anthracite industry and in other industries that have the same or similar problems.

ACKNOWLEDGMENTS

The information contained in this report was obtained from various officials of mining companies in the anthracite region, and by a study of installations in the region. Representatives of lime companies serving the area also contributed valuable information. Mr. S. H. Ash, chief, Safety Division, Bureau of Mines, and Mr. James Westfield, mining engineer, Bureau of Mines, offered many suggestions and assisted materially in the study. All assistance received is gratefully acknowledged.

DESCRIPTION OF LIME-TREATING EQUIPMENT

Four methods are employed to add the lime to the acid mine water. All methods develop a concentrated lime-water mixture or slurry that is fed into a storage reservoir or directly into the breaker pumping system. To avoid a repetition of words, the word "installation" will mean the equipment used to accomplish the foregoing purpose. A general description of each installation follows:

Screw Feeder

The screw feeder is used predominantly because of (a) the low initial cost; (b) the small space required for installation; (c) the small agitating or mixing chamber; and (d) the low maintenance cost. This is a dry chemical feeder. It consists of a hopper that holds seventeen 50-pound bags

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(850 pounds.) of hydrated lime, a worm-geared device that draws a definite amount of lime from the hopper, a mixing chamber where water mixes with the lime to form a slurry, and a slurry feed pipe that feeds into a storage reservoir or directly into the breaker pumping system. Figures 1, 2, and 3 show typical screw-feeder installations. An average installation costs $400. The motive power is obtained by a 1/2-hp. electric motor. The installations on the surface are placed near the discharge point of the mine water or adjacent to breaker pumps. Underground installations are placed at sumps that are utilized for breaker storage reservoirs. The most desirable installations are those that are near surface railroad sidings, as lime in carlots can then be unloaded and stored conveniently. Lime should be stored near the lime feeder to minimize handling; however, the lime shoul be stored in a dry place as the moisture absorbed tends to clog the discharg point of the hoppers.

One man can take care of lime storage, lime feeding, and the pumping units.

Vibrating Feeder

The vibrating feeder (dry chemical type) has a storage hopper that holds eighteen 50-pound bags (900 pounds) of hydrated lime. A vibrating chute draws a predetermined quantity of lime from the hopper and feeds it either directly to a flume that handles the water for breaker use where the mixing takes place, or into a short length of 12-inch-diameter pipe where a small portion of water is added to the dry lime to form a slurry. The mixture of lime and water is discharged into a storage reservoir adjacent to the intake pipe of the breaker pumps.

The motive power is furnished by electrically operated magnets, and the pulsations can be regulated to obtain the number of vibrations required to feed the predetermined quantity of lime. One man does the work necessary to run this installation.

Figures 4, 5, 6, and 7 show representative installations of the vibrating feeder. The cost of this installation is $400, the same as that of the screw feeder.

Disk Feeder

At one installation in the region, a flat circular disk revolving at a predetermined number of revolutions a minute draws lime from a hopper that holds twenty 50-pound bags (1,000 pounds). The dry lime drops into a sump below the feeder and is conducted, by gravity, through a pipe to a concrete storage flume having a capacity of one-half million gallons. The treated water in the flume is pumped to the desired places in the breaker. An installation of this type is more costly ($750 for feeder plus the cost of the concrete storage flume) than the first two installations described; however, the large storage flume permits a longer period for the reaction of the lime with the acid water and allows the sludge to settle, providing a clearer effluent for the breaker pump.

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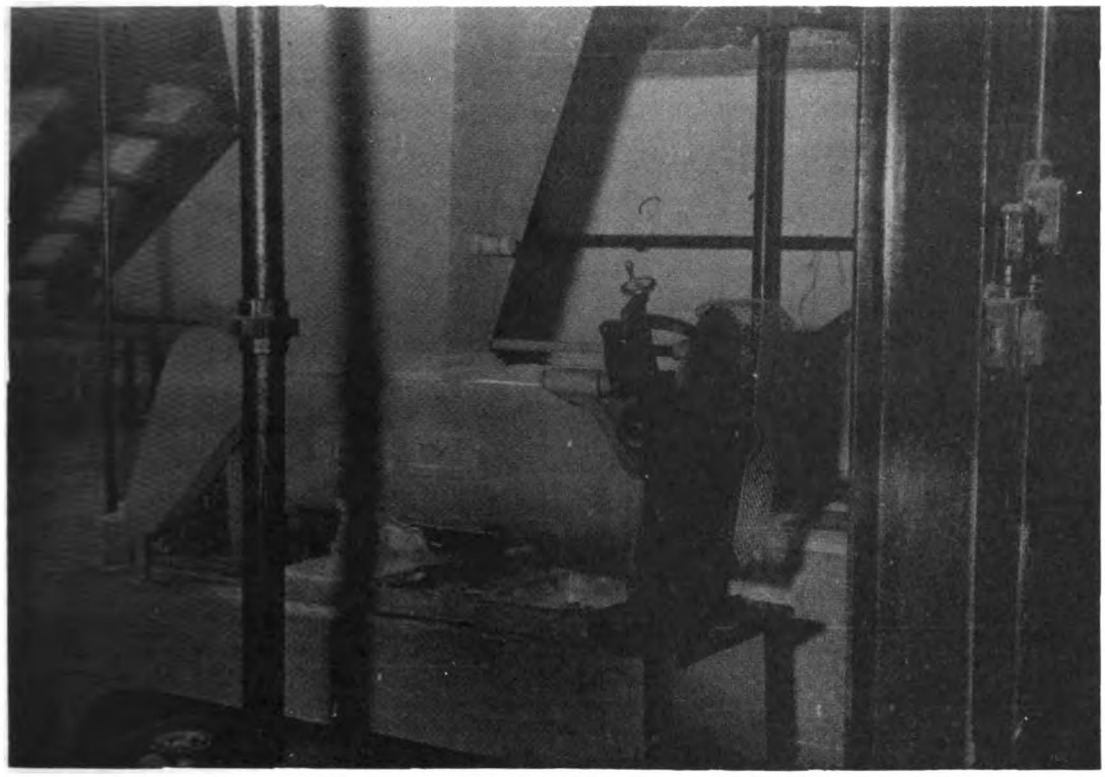

Figure 1. - Screw-feeder installation for lime treatment, showing hopper, mixing chamber, gear control, and starting switch.

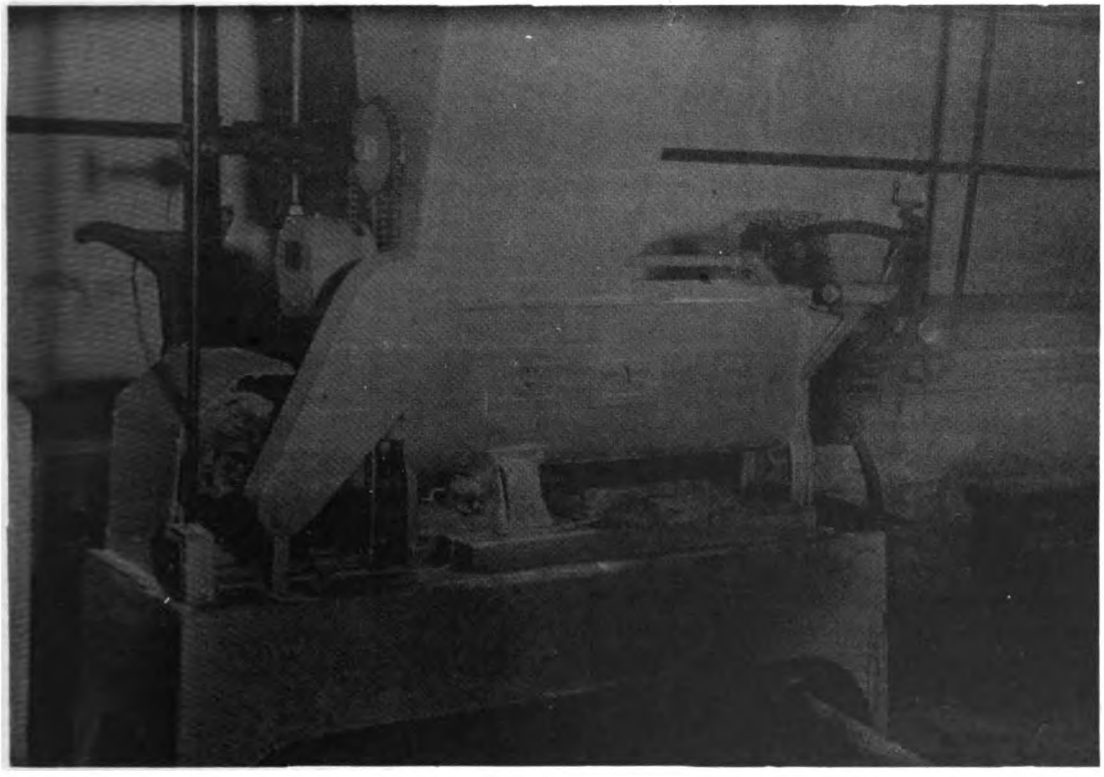

Figure 2. - Screw-feeder installation for lime treatment of acid mine water. Pipe in lower right corner carries lime slurry to sump.

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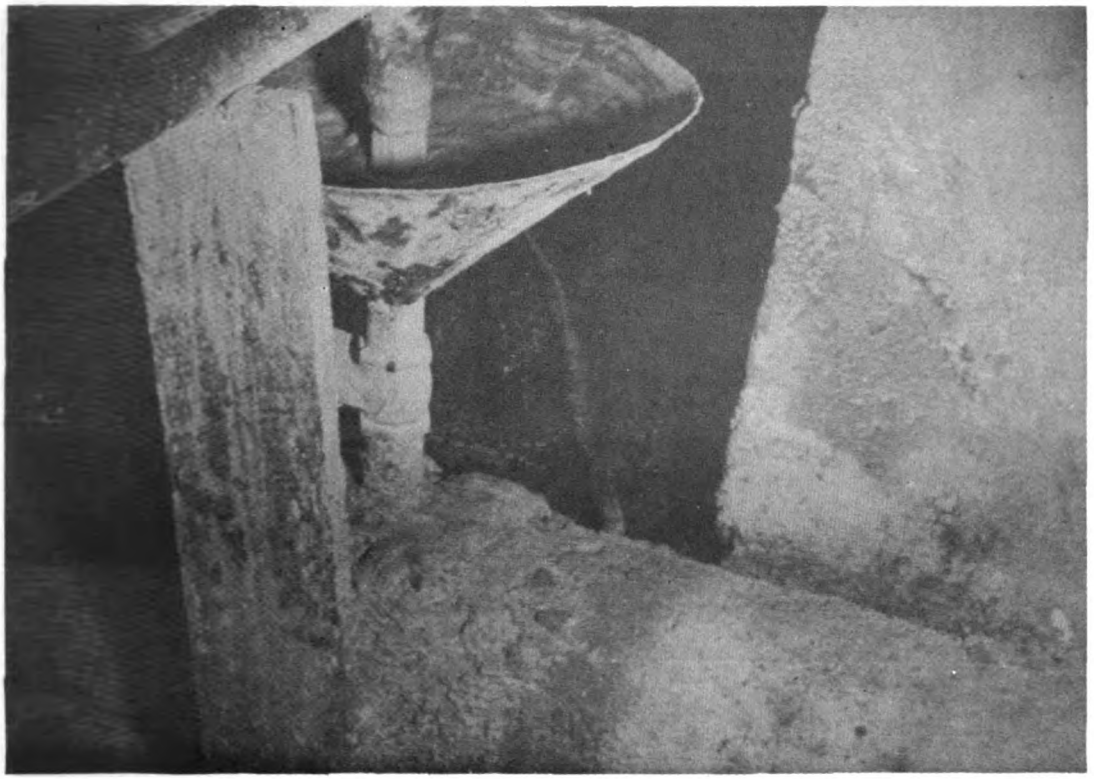

Figure 3. - Lime-slurry discharge entering direct into intake pipe of breaker water system.

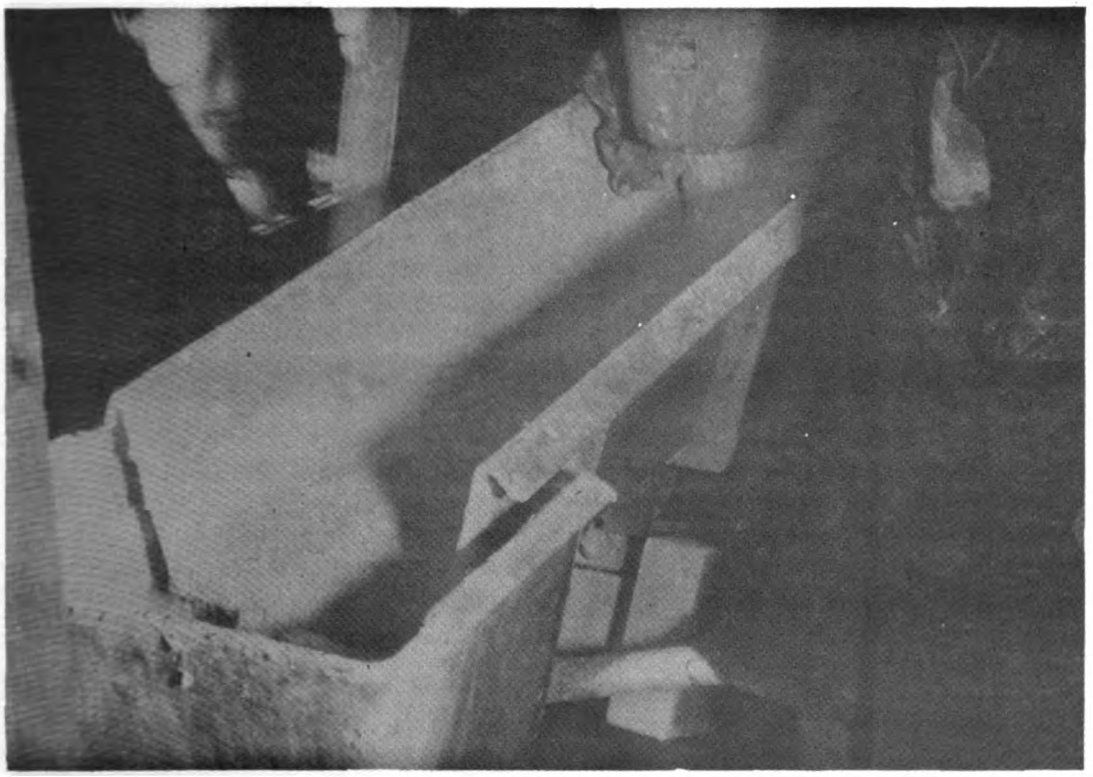

Figure 4. - Vibrating feeder for moving hydrated lime at a predetermined rate for mixing with water.

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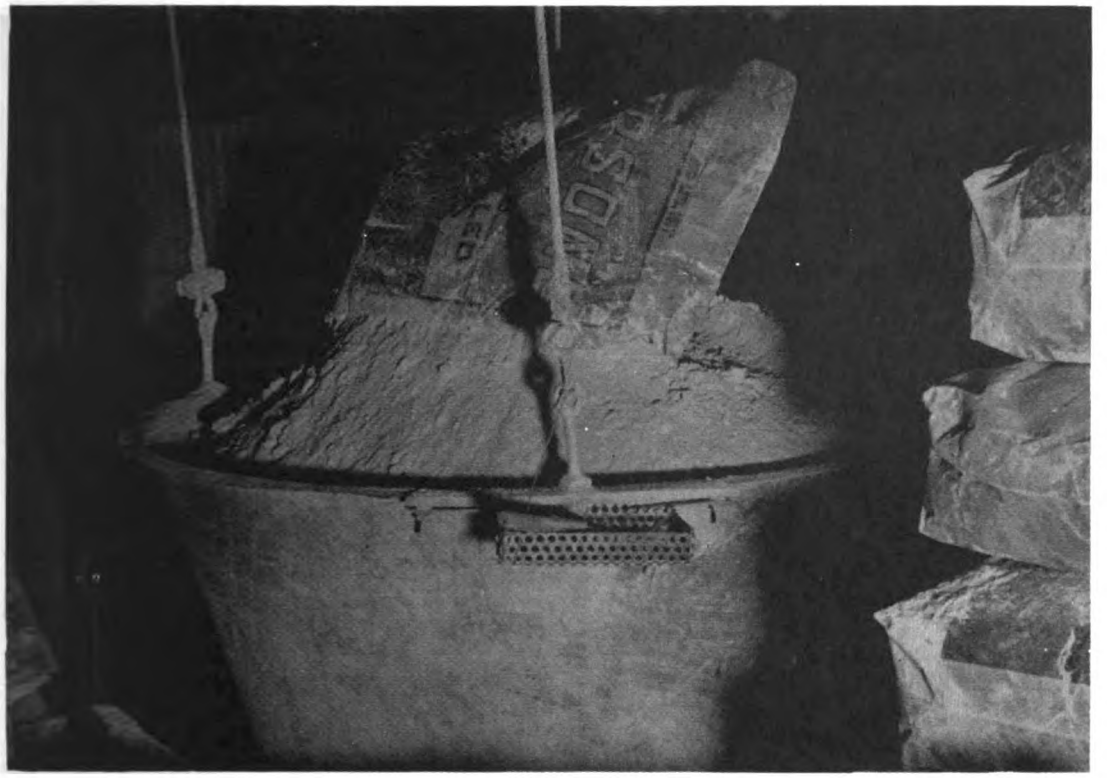

Figure 5. - Hydrated-lime hopper for vibrating-feeder system.

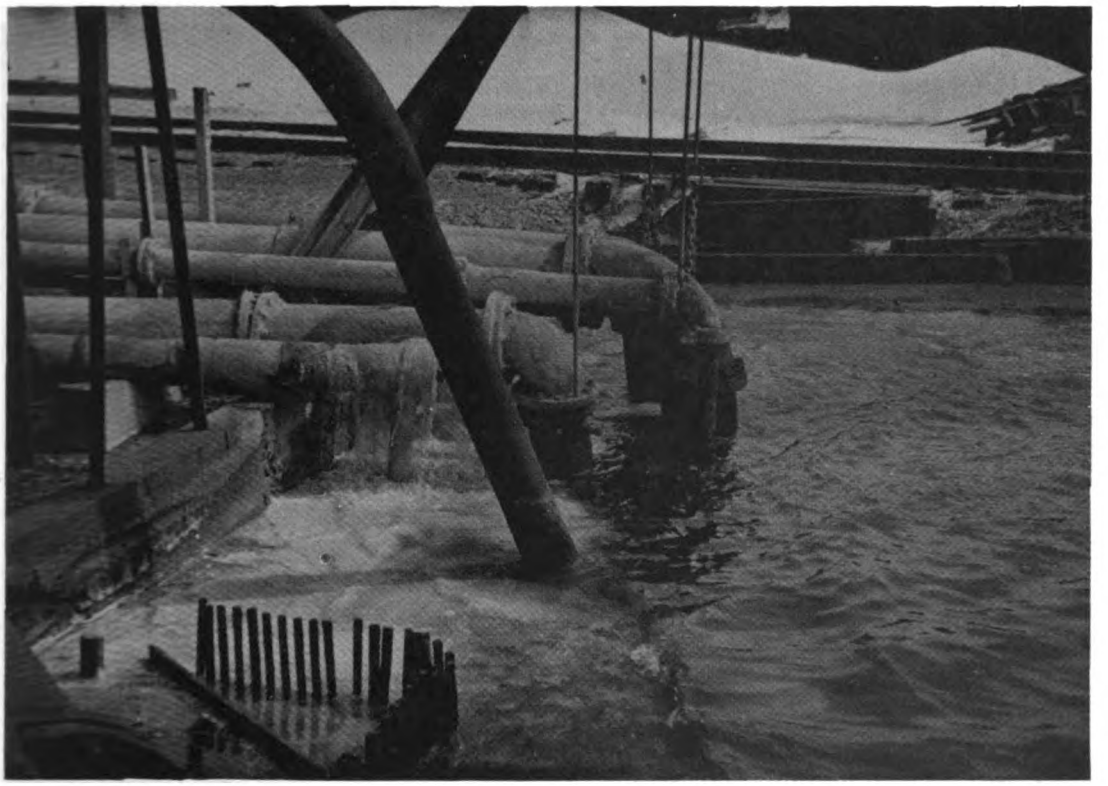

Figure 6. - Lime-slurry discharge from vibrating-feeder installation. Intake pipes from breaker water system draw treated water from reservoir.

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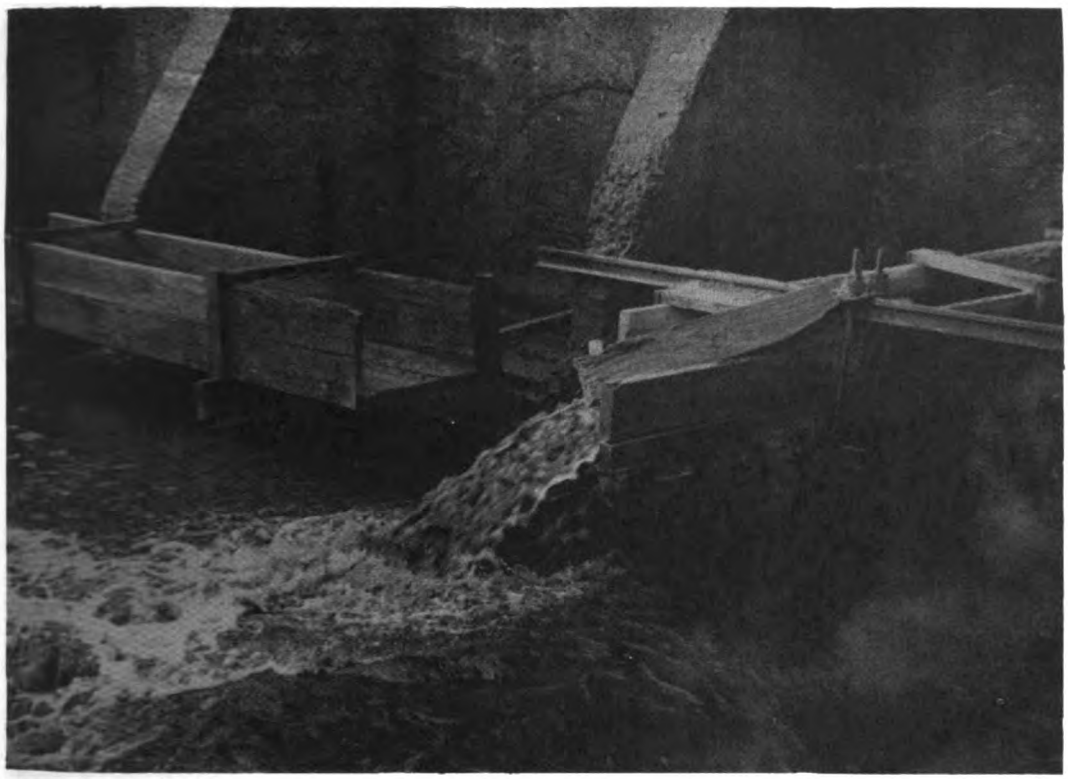

Figure 7. - Discharge of treated mine water to large storage reservoir.

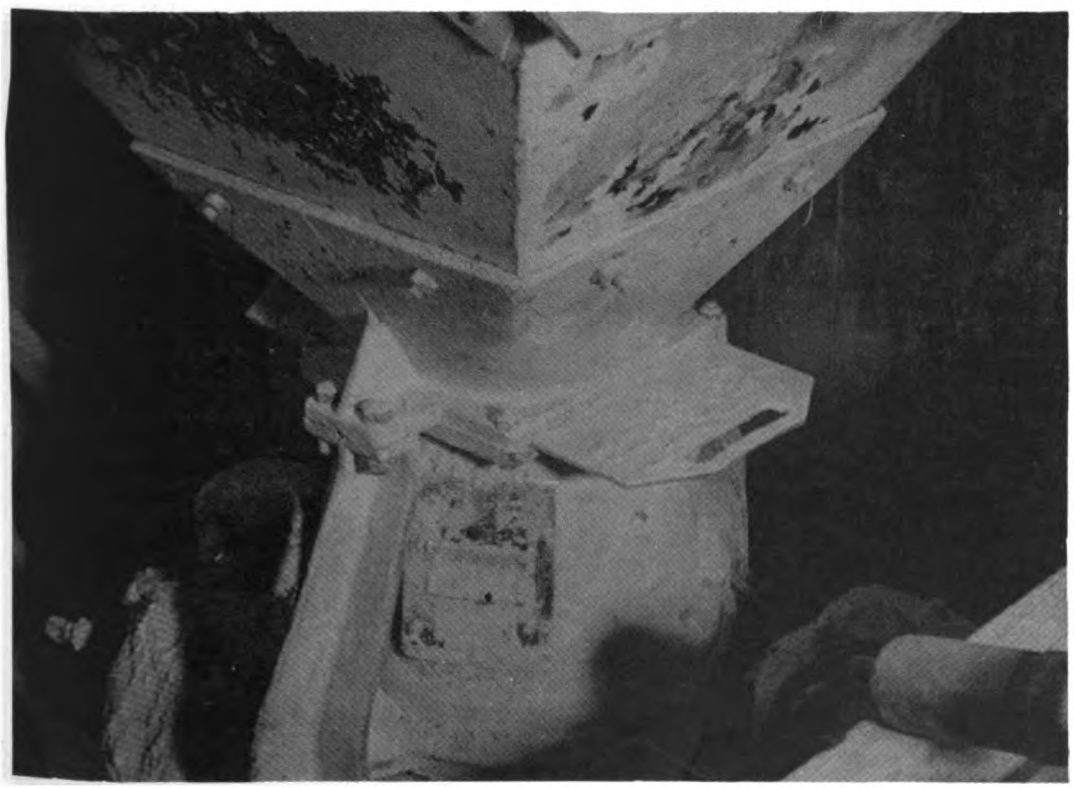

Figure 8. - Disk-feeder system drawing a predetermined amount of lime from a hopper.

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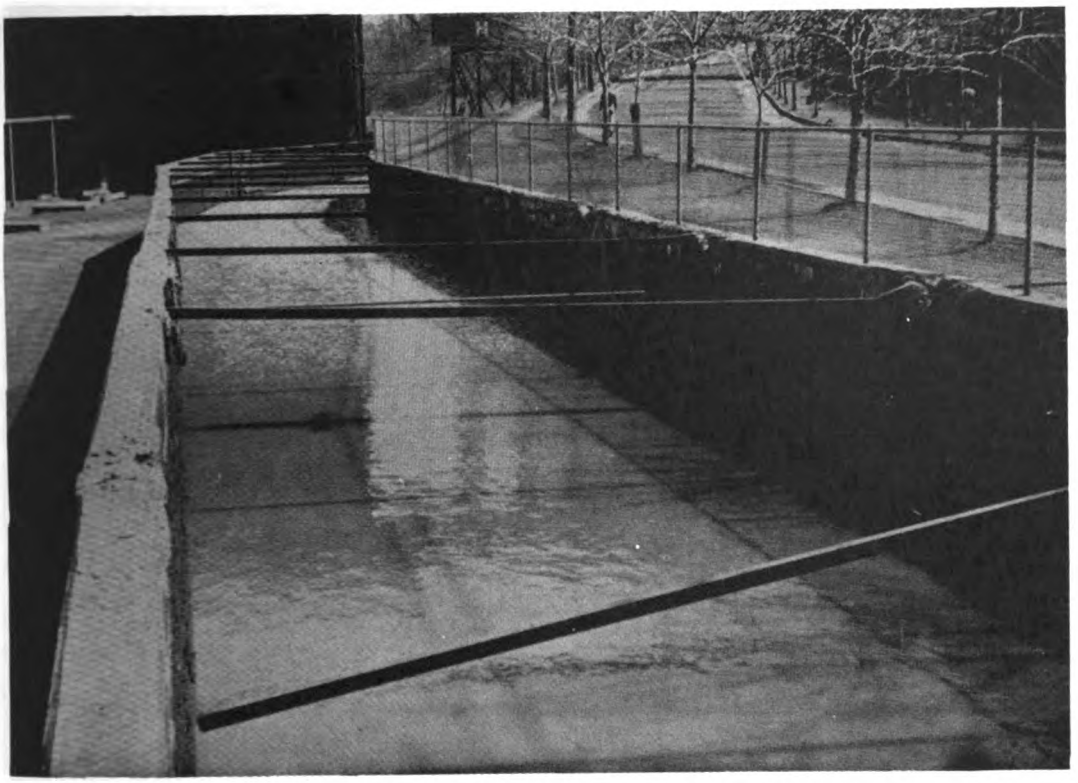

Figure 9. - Flume with a capacity of one-half million gallons for storage of treated mine water from a disk-feeder lime system.

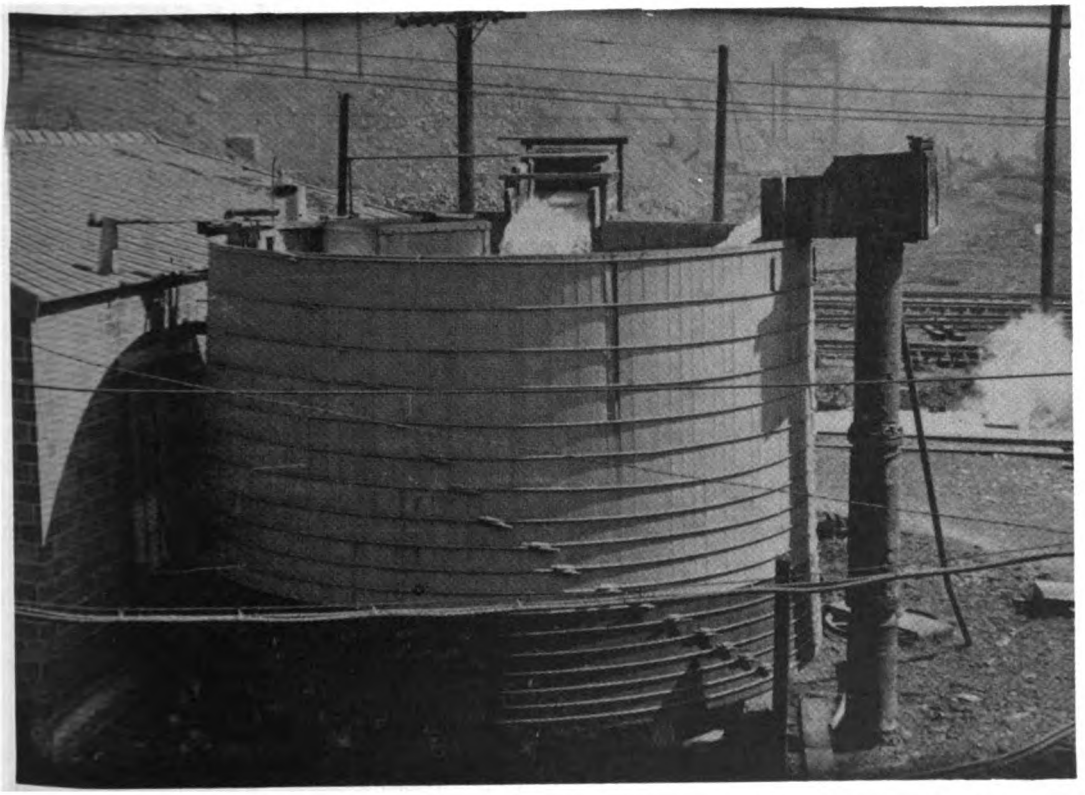

Figure 10. - Tank installations showing acid mine water entering at two locations and a lime slurry entering at a third location.

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The motive power of the disk feeder is furnished by a 1/2-hp. electric motor. One man operates and maintains the disk feeder and several pumping units. Typical views are shown in figures 8 and 9.

Mixing Lime and Water in Tanks

Dry, hydrated lime is conveyed to tanks that have a capacity of 7,000 gallons. The quantity of lime per inch of tank height is determined, and water is then mixed with the lime to form a slurry. The mixing action is accomplished in the tank by two direct motor-driven agitators that operate during the time the tank is being charged with lime and water and continues to operate 10 minutes. Two tanks are used in a series, one being charged and held in reserve while the other discharges the lime slurry into the breaker water system at a regulated number of inches of tank height an hour. Better retention of the lime in the water is accomplished by this type of treatment than by the screw-feed and vibrating-feed systems.

The lime-treating equipment consists of two mixing tanks, 14-feet in diameter and 6 feet in height; one feed tank, 24 inches in diameter and 24 inches in height; one circulating pump; one feed pump; and four direct motor-driven agitators. The cost of this installation is higher than the cost of others described.

One man charges the tanks, samples the water, and operates the pumps. Figure 10 shows lime slurry from this system entering a storage tank along with mine water.

LIME INFORMATION

Commercially, the term "lime" includes high-calcium lime that contains 90 percent or more of calcium oxide (CaO); magnesium lime containing 5 to 25 percent of magnesia (MgO) and 75 to 95 percent of calcium oxide; and high magnesian to dolomitic limes containing 25 to 45 percent magnesia and 55 to 75 percent calcium oxide. Chemically, pure lime is calcium oxide (CaO), but the commercial product contains impurities such as alumina, iron oxide, and silica.

Hydrated lime ($Ca(OH)_2$) is the only kind of lime used in the anthracite region. This lime is purchased in 50-pound paper bags and shipped to the breakers by railroad or truck. In the early experimental stages of treatment, other kinds of lime were used, such as granular limestone and agricultural lime, but the preliminary tests indicated that they were unsatisfactory. When water is added to quicklime, it slacks and forms lime hydrate ($Ca(OH_2)$). In this form lime reacts most effectively when used to treat acid mine water.

High-Calcium Lime

High-calcium hydrated lime is used at several lime-treating installations, but the total amount used is less than 25 percent of the lime used in the anthracite region. A typical analysis of high-calcium hydrated lime is as follows:

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	Percent
SiO_2 - insoluble	0.90
Fe_2O_3	.20
Al_2O_4	.60
CaO	73.00
CO_2	.80
MgO	.85
H_2O	23.65
Total	100.00
$Ca(OH)_2$ - available	95.00

A typical screen analysis for this lime is as follows:

	Mesh	Percent
Passing	30	100.00
Passing	100	99.99
Passing	200	98.00
Passing	325	96.50

The reaction rates of high-calcium hydrated lime and of dolomitic lime are very rapid and it is difficult to distinguish between the two. However, because sulfuric acid tends to form insoluble calcium sulfate, this slightly retards the reaction rate of the high-calcium lime. The formation of calcium sulfate is less when dolomitic lime is used, and the magnesium sulfate that is formed is soluble in water.

High-Magnesian or Dolomitic Lime

Over 75 percent of the lime used is high-magnesium or dolomitic lime. A typical analysis is as follows:

	Percent
SiO_2 - insoluble	1.2
Fe_2O_3 and Al_2O_3	.5
CaO	47.4
MgO	34.0
CO_2	.4
H_2O	16.5
Total	100.0

The following screen analysis is typical of high-calcium hydrated lime:

	Mesh	Percent
Passing	20	100.00
Passing	30	100.00
Passing	60	99.90
Passing	100	99.70
Passing	200	96.00

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The solubility of the two hydrated limes in water is relatively low, varying from 0.2 gram a liter for high-calcium lime to a smaller amount for high-magnesian lime. Most systems apply hydrated lime and water in the form of a slurry. Sedimentation occurs when such slurries are used, although by the use of most refined limes, sedimentation is slow and a mild agitation will prevent it.

When the slurry is admixed with acid mine water, the dissolved lime reacts with the acid in solution. As soon as this lime is consumed, additional lime passes into solution from the suspended particles in the slurry. The amount of suspended lime consumed depends on the acidity of the mine water and the time available for chemical activity.

The quantity of hydrated lime necessary to treat acid mine water depends on the end point sought, the acid content of the mine water, and the amount of water to be treated. One breaker in the region is treating 4,000 g.p.m. with 21 pounds of hydrated lime per minute for 16 hours a day. To obtain the desired results, the daily consumption is 400 bags or 20,000 pounds. The cost of hydrated lime is uniformly $9.00 a ton, f.o.b. the lime-manufacturing plants. The freight rate from the nearest lime manufacturing plant is $2.00 to $2.75 a ton, depending on the shipping point in the region.

The consumption of hydrated lime at some breakers varies from 1/2 pound to 13 pounds per minute (200 to 11,000 lb. a day), and the treatment is on a flow of 600 to 6,000 g.p.m. of mine water. Table 1 shows data on lime-treatment installations.

Other Forms of Lime for Treatment

The possibility of using quicklime instead of hydrated lime to treat mine water has been discussed. To do this it would be necessary to install a plant to hydrate the quicklime which would cost about $3,000. However, quicklime can be purchased in bulk carlots at a lower cost per ton than hydrated lime, and there would be a saving on the cost of the bagged product and a higher percentage of CaO available. If an appreciable amount of lime is used, the initial cost of the hydrated-lime plant could be amortized in several years by savings resulting from the use of quicklime. An example of the savings in cost is as follows:

Hydrated lime	-	$ 9.00 a ton (bagged in 50-lb. bags)
Freight	-	2.50 a ton
		$11.50 a ton

Available CaO in hydrated lime - 70 percent

$$\frac{\$11.50}{70} = \$0.164 \text{ a unit of CaO}$$

Quicklime	-	$ 7.65 a ton (bulk carlots)
Freight	-	2.50 a ton
		$10.15 a ton

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Available CaO in quicklime -94.5 percent

$$\frac{\$10.15}{94.5} = \$0.107 \text{ a unit of CaO}$$

When units of CaO available for neutralization are compared, quicklime shows a 34.8-percent saving in cost.

If a quicklime hydrating plant is used, special precautions must be taken to prevent explosions and burns. When water is admixed with quicklime, considerable heat is generated and steam evolved to the extent that explosions occur and hot materials can be thrown from the mixture; therefore, safety precautions must be taken to prevent injuries. Moreover, quicklime dust can cause severe eye injuries and body burns. Goggles and gloves should be worn by those mixing quicklime and water.

Information regarding the prevention of skin irritation from lime dust by the use of cream or ointment and through personal cleanliness has been published(6).

The system for hydrating quicklime can be planned so that through the use of automatic unloading devices, conveyors, etc., very little contact is made with quicklime. By the use of such devices, safety is increased and health hazards are minimized for employees.

Another method of lime treatment of mine water is the use of pulverized (4- to 6-mesh) limestone(7). Laboratory tests on the neutralizing power of limestone have been conducted at the Missouri School of Mines and Metallurgy A solution containing 200 p.p.m. of sulfuric acid was percolated through a bed of minus 4- plus 6-mesh limestone assaying 98 percent of calcium carbonate(2). The results are summarized in table 2.

The pulverized product can be placed in a trough of adequate size, so that mine water will percolate upward through the limestone. Any precipitate of calcium sulfate will clear itself with upward percolation and not reduce the effectiveness of the limestone.

PROCEDURES EMPLOYED TO DETERMINE THE ACIDITY OF MINE WATER

The procedures employed to determine the acidity of water vary as to (a) the methods used to express results; (b) the equipment used to make tests; (c) the frequency of tests; and (d) the range of the desired end point of treated water.

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TABLE 1. - Data on representative lime-treatment installations for treating acid mine water in the anthracite region

Installation	pH[1/] of initial water	Total water treated, g.p.m.	Hydrated lime used a day pounds	Pounds of lime to 1,000 gal. water	Method of treatment	pH[1/] of treated water
A	2.9	3,300	1,550	1.1	Screw feeder	4.1
B	2.9	1,850	1,400	1.8	do.	4.1
C	2.9	2,300 to 3,400	1,400	.9 to 1.4	do.	4.1
D	3.0	2,800	2,000	2.0	Direct tank	6.6
E	5.0	3,500	1,200	.8	do.	6.5 to 7.0
F	4.2	2,500	1,650	1.2	do.	6.5 to 7.0
G	4.0	4,000	6,000	1.8	Screw feeder	6.5
H	Unavailable	2,000	1,000 to 2,000	1.2 to 2.4	do.	5.5
I	do.	600	300 to 4,000	1.2 to 15.8	do.	5.5
J	2.7	4,000	20,000	5.2	Vibrating feeder	5.0
K	Unavailable	4,000	9,000	2.6	Screw feeder	5.0
L	do.	3,700	10,850	3.4	do.	5.0
M	3.0 to 5.5	1,500	200 to 2,500	.3 to 3.9	do.	5.5 to 7.0
N	Unavailable	3,500	1,900	1.3	do.	5.6
O	do.	4,500	2,300	1.0	do.	6.8
P	do.	3,500	4,800	2.9	do.	6.8
Q	do.	1,200	1,050	2.1	do.	5.6
R	do.	2,500	1,750	.8	do.	5.8
S	do.	6,000	8,300	1.6	Vibrating feeder	5.0
T	3.8	3,000	2,000	1.6	Disk feeder	6.9
U	Unavailable	3,000	2,250	.9	Screw feed	6.5
V	do.	4,200	2,750	.8	do.	6.5

1/ See p. 10 for definition of symbol "pH".

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TABLE 2. - Neutralization of free acid by percolation through a bed of 4- to 6-mesh limestone

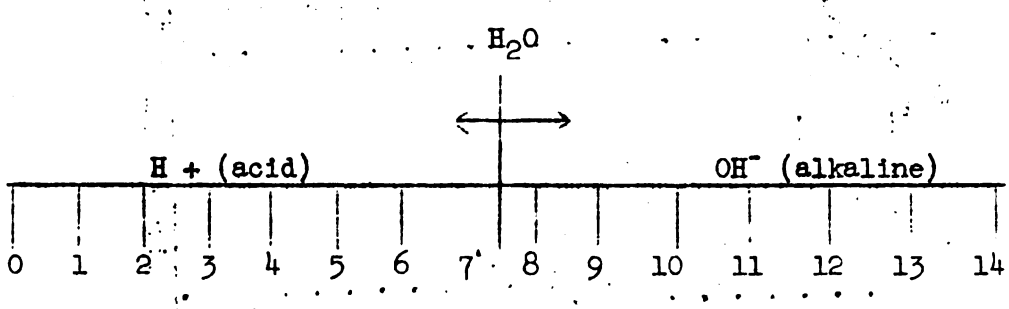
Cumulative time of contact, seconds	pH 1/	H_2SO_4, p.p.m.
0	-3.0	200
11	5.5	Trace.
19	6.0	do.
27	6.3	do.
45	6.9	do.
57	7.1	None.

1/ See p. 10.

Methods Employed to Express Results

A chemical concept that is common to all problems in water chemistry and also useful in many other arts is the "pH" or hydrogen-ion concentration. The hydrogen-ion concentration is essentially an accurate method used to express the degree of acidity or alkalinity. The pH value is defined as the negative logarithm of the concentration. Because water is the most definitely neutral chemical substance known, it has been determined from the equilibrium constant of ionized water that a pH of 7 indicates chemical neutrality. Values of pH above 7 are alkaline, and those below 7 are acid. Because of the logarithmic scale used, each value in it is 10 times more than the one below and one-tenth as much as the one above. Tables 3 and 4 serve to clarify this point. Steiner(5) has discussed, in detail, what pH means and how it is measured.

TABLE 3. - Diagram to indicate acidity and alkalinity



Equipment Employed

The most common method employed to make pH tests is accomplished by colorimetric-slide comparator sets. The slides contain indicators, and each one covers a portion of the pH range; the indicators give different color reactions from the indicator immediately adjacent to it and give different shades of color over its own range. Standard slides and indicators used to test mine water are as follows:

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pH range of slide	Indicator
2.4 - 4.0	Benzo yellow
3.0 - 4.6	Bromophenol blue
3.8 - 5.4	Bromocresol green
4.4 - 6.0	Methyl red
5.2 - 6.8	Chlorophenol red

TABLE 4. - H-ion concentration

pH value	Values showing intensity of acidity and alkalinity	Ionizable H a liter, grams	
0	10,000,000	1.0	10^{-0}
1	1,000,000	.1	10^{-1}
2	100,000	.01	10^{-2}
3	10,000	.001	10^{-3}
4	1,000	.0001	10^{-4}
5	100	.00001	10^{-5}
6	10	.000001	10^{-6}
7	1	.0000001	10^{-7}
8	10	.00000001	10^{-8}
9	100	.000000001	10^{-9}
10	1,000	.0000000001	10^{-10}
11	10,000	.00000000001	10^{-11}
12	100,000	.000000000001	10^{-12}
13	1,000,000	.0000000000001	10^{-13}
14	10,000,000	.00000000000001	10^{-14}.

The colorimetric determination is not precise, but it is accurate enough for general tests of water. Standards can be obtained in steps of 0.2 pH, so that results may be determined to the nearest 0.1 value.

Frequency of Tests

Acid mine water is tested by company chemists, pumpmen, purchasing agents, engineers, or lime-company representatives. After a preliminary examination of the mine water, the determination of lime charge necessary, and tests on treated water, the only test then made is of the water used in the washery. A few companies require at least two daily tests of the water for use in the washery, some require one, and others require them once a month or several times a year.

The desirable pH of the treated water varies with the opinions of those in charge of the lime-treating installations. The initial mine water may test from 2.7 pH to alkaline (more than 7.0 pH), but most treatments are on water having a pH that ranges from 2.7 to 4.0. The final pH varies from 4.1 to 7.0 pH. Some believe that at 4.0 to 4.4 pH, when the free acid is precipitated, the "sting" or "bite" is removed and additional treatment is not warranted. The majority believe that the water should be treated until a pH of at least 5.4 is attained or preferably a pH that ranges from 5.8 to 6.0.

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At a pH of 4.4, a leveling effect or buffer action is experienced. This is caused by the presence of dissolved iron salts - particularly ferrous sulfate. After all the iron salts have been precipitated, the pH will again rise at a uniform rate.

Mine water varies in pH from season to season because of a low or a high water-table. During a rainy period, the pH may indicate more acid conditions for a few days because of water running through deposits of "sulfur mud" or "yellow-boy," and then the acidity of the mine water will drop below that of normal mine water. Usually, during low-water periods, the pH of the mine water is low (highly acid), and more lime is required for treatment. A rough estimate used for lime requirements is that 100 pounds of hydrated lime will raise the pH value of 100,000 gallons of water 1 pH.

Analytical results of water samples are sometimes shown as parts per million (p.p.m.) or as grains per gallon (gr./gal.). One part per million equals one ten-thousandth of 1 percent (0.001 percent). It is a measure of proportion by weight and is equivalent to a unit weight per million unit weights of solution.

The older practice of reporting results in grains per gallon is gradually being superseded by the more convenient expression of parts per million. The results can be converted from one form to the other, because 17.1 parts per million is equivalent to 1 grain per U. S. gallon. A factor used to determine the lime required to neutralize acid mine water when expressed in grains a gallon is shown as follows:

> Grains of total sulfuric acid X 0.10804 = pounds of hydrated lime to neutralize 1,000 gallons of water.

ADVANTAGES DERIVED FROM TREATMENT BY LIME

It is difficult to refer to the lime treatment of acid mine water as a tangible asset, because appraisals on replacement parts, life of parts, labor costs, maintenance costs, and other related items are not usually kept in cost-account records. Statements by individuals in charge of treatment processes infer that before the mine water was treated to prevent corrosion it was necessary either to replace pipe, chute linings, screens, and other metal equipment every few months or to use expensive acid-resistant alloys or extra-heavy metal. With lime-treatment installations in use, little repair or delay is encountered other than normal wear, and it is possible to use lighter and cheaper metals.

COSTS

One company in the region reported that $10,000 was saved in one year by installing a lime-treatment system at one of its breakers. This saving was accomplished by a reduction in the costs of materials and maintenance. Another company indicated a reduction of $1,100 to $3,000 a month in breaker-material upkeep.

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REPLACEMENT OF MATERIAL

Breaker equipment receives harsh treatment primarily from the abrasive action of pulverized coal and rock, from silt in high-pressure water sprays, and from sand when sand preparation is used. However, extra-heavy metals, alloys, rubber, and glass are used to prevent abrasion and corrosion. Where acid mine water is required for coal-preparation purposes, breaker officials have learned from the experiences of many break-downs, frequent and expensive replacements, and the cost of a large maintenance crew that the problem is greatly alleviated by the installation of a lime-treatment system.

Where the acid mine water is treated with lime, it has been possible to use steel pipe instead of cast-iron pipe, lightweight metal for chute linings in place of extra-heavy metal linings, and cast iron for parts in pumps, valves, and screens instead of parts made of acid-resistant alloys. Consequently, substantial savings are made by a reduction in the first cost of such materials and the reduced costs resulting from longer and more satisfactory wear.

CONCLUSIONS

1. Four types of installations are utilized to treat acid mine water for use in breakers in the anthracite region. The installations vary in the method of drawing lime from the storage hoppers, in the manner of admixing the lime with water, in the length of time that the lime is in contact with the acid mine water before use, and in the way the lime-water solution enters the breaker water system. The screw-feed method of admixing hydrated lime with the acid mine water is more widely used than the vibrating-feed method, disk-feed method, or direct-tank preparation method. This is because of the low first cost, the small space required for the installation, the small mixing chamber, and the low maintenance cost.

2. At present, hydrated lime is the only kind of lime used in the anthracite region for acid mine-water treatment. Other kinds of lime compounds are mentioned, as their possible use may prove more economical.

3. Lime treatment is usually on acid mine water having a pH that ranges from 2.7 to 4.4. This treatment reduces the acid content so that the pH of the water ranges from 3.9 to 7.0. The majority of individuals responsible for lime-treatment installations treat the acid mine water to obtain water having a pH of at least 5.4 and preferably a pH in the range of 5.8 to 6.0.

4. The most common method for determining the pH of water is the use of colorimetric-slide comparator sets because of their simplicity, practical accuracy, and the short time necessary for making a determination.

5. The advantage of treating acid mine water with lime is shown by comparing the cost of breaker materials before and after treatment and by the favorable statements of individuals in charge of the lime-treatment installations. When only highly acid mine water was available for washery use, many break-downs occurred, frequent and costly replacements were

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necessary, and large and costly maintenance crews were employed. This was necessary to combat the effects of corrosion. Since treatment systems have been used, it has been possible to use lightweight metals for equipment and obtain far more safisfactory and efficient service.

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